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Qualitative chemical measures to indirectly assess quality of natural/uncured, organic bacon compared to traditionally cured bacon.

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ABSTRACT

There is an increasing concern about potential quality variability of natural/uncured and organic processed meats due to the processing modifications necessary for these products. In addition, microbial safety of these products needs to be evaluated. The goal of the study was to identify the sources of variability in quality of natural/uncured, organic bacon products emerging on the market to provide information relevant to future consumption and safety of these products.

The objective of this study was to quantify the quality characteristics of commercial brands of bacon manufactured without the direct addition of nitrite or nitrate and to compare these products to traditionally cured brands. A total of 12 brands of bacon were analyzed for color, total pigment (TP), cured pigment concentration (CP), % cured color (PCP), water activity (a_w), TBARS, pH, salt content (NaCl), residual nitrite (NO2), moisture, fat, and protein. Results from this study revealed that color scores, cured pigment, % cured color, TBARS, salt content, residual nitrite, moisture, and fat were different between the brands of bacon ($p<0.05$). Comparing overall means were higher between control (traditionally cured) vs. natural/uncured labeled bacon, revealed moisture was different. Control (traditionally cured) vs. organic category overall means showed a*, b* value of obliquus abdominis muscles, PCP, TBARS, moisture, and fat were different from each other ($p<0.05$). The a*, b*, PCP, and moisture values were lower while TBARS and fat were higher. The results from this project will be used to help prepare guidelines for manufacturing products that possess consistent quality natural and organic bacon products. These results will help processors likely sources of quality issues in natural and organic bacon.

Keywords: bacon, quality, natural, uncured, organic, nitrite

CHAPTER 1. GENERAL INTRODUCTION

1.1.1 Hypothesis:

The hypothesis for this work is that there is more variability in quality of natural, uncured, and organic bacon compared to traditionally cured brands that are commercially available. It is proposed that increased variability in residual nitrite concentration and the lack of established production guidelines for natural and organic bacon are two of the major factors for the hypothesized differences in quality between natural/uncured and organic processed bacon relative to traditionally cured bacon.

1.1.2 Objectives:

1. Compare quality attributes between twelve different commercial brands of bacon to determine if product characteristics are significantly different, especially residual nitrite.
2. Assess potential relationship between residual nitrite and safety of natural/uncured and organic commercial bacon

CHAPTER 2. REVIEW OF LITERATURE

2.1 Introduction

Growth of natural, uncured, and organic bacon products has lead to an increased concern for quality and safety of these products without direct addition of sodium nitrite or nitrate. Traditionally cured bacon has been proven to be consistently of high quality and safe to consume when cured by conventional methods. However, as more and more processors enter the market with natural and organic products, standards for production need to be established to ensure quality and safety of this unique group of bacon products. Processors need to be able to provide consistent quality natural and organic bacon to ensure consumers are receiving a product similar to what they would expect from traditionally-cured bacon. With the increased number of processors entering the market with little to no guidelines for producing naturally cured, uncured, or organic bacon, an increase in variation between brands of bacon on the market is likely to be reflected in the chemical properties and quality of bacon.

This study will determine the extent to which variation in natural and organic bacon quality attributes exist between twelve different commercial brands of bacon. The study will also consider implications that modified processing procedures used for natural and organic bacon has for consumer safety. We hypothesize that the quality of bacon may be correlated to the amount of residual nitrite/nitrate levels found in these emerging bacon categories. Because the curing process is accomplished with use of vegetable juice powder, which is high in nitrate, as a source of nitrite for curing the bacon products, this is likely to result in an inconsistent level of nitrite being added. Variability in quality attributes between conventionally cured commercial bacon brands can be observed on the market and is likely to be greater with natural and organic products, because the latter may contain variable amounts of nitrite. Sodium nitrite has many functions in cured meats and has long been used in processed meats to achieve consistent quality and safety. With inconsistency in quality, concern for repeat purchases is an issue to the industry due to the possibility of a negative purchasing experience. Variable concentrations in ingoing and/or residual nitrite have implications for microbial safety.

2.2 Background of Sodium Nitrite

Sodium nitrite has been used since the Roman times ~3000 B.C. as a method to cure and preserve food (Pegg & Shahidi, 2000). Although sea salt was first believed to be the main active curing ingredient for preservation, it was contaminated with nitrate (Honikel 2008). Sea salt containing nitrate was eventually known as salt peter (potassium nitrate) (Cassens and others 1978). Nitrite since then has been shown to be the active component responsible for preservation, after being reduced from nitrate through bacterial reduction. Today, nitrate and nitrite and its functionality in meat processing (besides preservation) have been recognized. Nitrate and nitrite play important functions in quality and safety of cured meats such as imparting cured flavor, color improvement, acting as an antioxidant, and as an effective antimicrobial agent.

Nitrate is not commonly added directly to bacon or other cured meat products due to the need to undergo enzymatic processes through bacterial conversion to form the active component nitrite, thus slowing down the curing process (Azanza and Rustia 2004; Tarté 2009). Residual nitrite levels in meat have also seen a decline over the years since the 1970’s due to the dangers of nitrosamines being formed from nitrites and secondary amines in meat as stated by the National Academy of Sciences (National Academy of Sciences 1981, 1982, Cassens 1997). Sodium nitrite is a white crystalline powder that is soluble in water (Tarté 2009). In the United States, the use of nitrate is prohibited in certain meat products and the ingoing levels of nitrite are strictly regulated (USDA, 1995).

2.2.1 Functionality of Sodium Nitrite in Cured Meats

Sodium nitrite provides four key functions in cured meats. Sodium nitrite has been shown to be involved with cured flavor and color development, act as an antioxidant, and as an antimicrobial agent to ensure safety to consumers (Wolff and Wasserman 1972; Honikel 2008). In addition nitrite has been shown to extend the shelf life of meat products through its antioxidant and antimicrobial properties. The use of nitrite produces a cured meat product that is highly acceptable to consumers.

Cured Flavor

The volatile flavor components that are responsible for cured meat flavor have not been completely identified and are not fully understood. Some researchers have suggested that nitrite functions as an antioxidant, suppressing lipid oxidation, and therefore, provides a cured flavor not seen in meats without nitrite. Bacon has a high content of fat, thus making nitrite important for cured flavor if the flavor is related to suppression of lipid oxidation. Pork fat contains about 37.1% saturated fatty acids, 44.9% mono-unsaturated fatty acids, and 11.3% poly-unsaturated fatty acids (Vandendriessche 2008). As consumers demand leaner pork, there has been an increase in polyunsaturated fatty acids from the diet, which makes the fat in bacon more prone to lipid oxidation (Channon and Trout 2002). On the other hand, in braunschweiger without nitrite there was no difference in flavor, but a difference in color was observed (Chyr and others 1980a). Other researchers have concluded that nitrite has a minimal effect on cured meat flavor (Jeremiah and others 1996). Most researchers have concluded that there is a distinct flavor in cured meat products from nitrite, but the mechanism of action is not clear.

Cured Color Development

Cured color development in cured meat results from the formation of NO-myoglobin with the iron in its Fe^{2+} or ferrous state (Honikel 2008). Nitrosylmyoglobin is the bright red (pink) pigment formed in cured meats while nitrosylhemochrome is the cured pigment after cooking (Wolff and Wasserman 1972). Several different states of myoglobin are shown in Table 1. The oxidation state of iron in myoglobin, a sarcoplasmic protein, is responsible for the type of color seen. Myoglobin exists in three main forms of color in fresh meats depending upon the oxidation state of iron and the ligand that is bound. A concentration as low as 50 ppm of ingoing nitrite will achieve good cured color development with packaging material that provides high barrier films and vacuum levels (Lin and Sebranek 1979). The amount of residual nitrite may affect the sustainability of cured color in processed meats (Cassens and others 1978; Tarté 2009). Nitric oxide is the active compound shown to produce cured color development.

Table 1. Pigments found in fresh, cured or cooked meat (modified from Lawrie, 2006)

Pigment	State of Iron	Ligand	Color
1. Myoglobin	Fe ++	None	Purplish-red
2. Oxymyoglobin	Fe ++ or Fe +++	Oxygen	Bright red
3. Metmyoglobin	Fe +++	None	Brown
4. Nitric oxide myglobin (nitrosomyoglobin)	Fe ++	Nitric Oxide	Bright red (pink)
5. Nitric oxide metmyoglobin (nitrosometmyoglobin)	Fe +++	Nitric Oxide	Crimson
6. Metmyoglobin nitrite	Fe +++	None	Reddish-brown
7. Nitrosylhemochrome	Fe +++	Nitric Oxide	Bright red (pink)

other forms of pigment are found, only seven common pigments shown in table

Antioxidant

Nitrite acts as an indirect antioxidant by sequestering oxygen which prevents autooxidation reaction of lipids, and hence retards rancidity in meat products (Honikel 2008). In addition to sequestering oxygen, the indirect effect may also help in preserving the cured meat color by preventing color fading. Lipolytic bacteria may play a role in rancidity development by increasing oxidation activity. Besides fat content, packaging film permeability affects the level of exposure of products to oxygen, which is an important factor in controlling rancidity development (Chang and others 1983).

Antimicrobial

Nitrite has been shown to prevent growth of *Clostridum botulinum* and *Listeria monocytogenes*, but the mechanism of action has not been clarified (Tompkin 2005, Sebranek and Bacus 2007). In braunschweiger, nitrite was shown to inhibit the growth of enterococci which is responsible for a perfumy odor (Chyr and others 1980b). Nitrite has been shown to inhibit the division of *C. botulinum* vegetative cells while the residual amount of nitrite in meat prevents *C. botulinum* growth (Wolff and Wasserman 1972). It has been proposed that the iron-sulfur proteins or enzymes such as ferredoxin in vegetative cells of *C. botulinum* react with nitrite to from iron-nitric oxide complexes which inhibit ferredoxin, therefore, inhibiting growth (Reddy and others 1983). Nitrite acts as both a bacteriostatic and bacteriocidal agent depending upon other environmental factors.

Residual nitrite may play a key role as an antibotulinal agent in meats along with pH (Reddy and others 1983, Tompkin 2005). The amount of residual nitrite declines through heating and over storage time (Cassens and others 1978). Higher residual nitrite amounts can be found in high fat bacon compared to lean bacon (Amundson and others 1982b). Other hurdles found in meat such as salt content, water activity, pH, and other food additives are likely to affect the role of nitrite and nitrate in keeping meat safe to consume.

Nitrite Chemistry

The chemical reactions that nitrite undergoes in meat are complex and is still not fully understood. Nitrite can be an oxidizer, reducer, or nitrosylating agent in meat (Sebranek and Bacus 2007). Nitrite can be oxidized to produce nitrate in meat products and has been shown to produce nitrogen gas. Nitrite can also react with salt resulting in antioxidant and antimicrobial activity (Sebranek and Fox 1985). Although nitrite can undergo many chemical reactions, its complete mechanism of action in cured meat has not been determined or verified for all of its functions.

2.2.2 Nitrate, Nitrite Sources

Nitrate is the precursor of nitrite. The major dietary intake of nitrate from food comes from vegetables, water supplies, and to a much lesser extent nitrate additives in processed meat (Wolff and Wasserman 1972). According to Cassens (1997), the average daily nitrate intake is 121 mg with 85% from vegetables, 5% from preserved and cured meat and 5% from cereal products. However in the case of nitrite, the human diet receives 39% from cured meat, 34% from baked goods and cereals, and 16% from vegetables. The National Academy of Sciences (1981) reported that vegetables such as beets, celery, lettuce, and spinach contain high levels of nitrate. Vegetables can contain up to 3,000 ppm of nitrate (Cassens and others 1978). Nitrate is also found and secreted in the human saliva and is usually excreted out with urine (Magee 1982). Nitrate in water can come from septic tanks, municipal sewage, nitrogen fertilizers, feedlots, and from areas where there is a high density of animals or humans (Shirley 1975). Nitrate is of concern because it can be reduced to nitrite in the human body or by bacteria which can be toxic in high concentrations. High concentrations of nitrite can lead to nitrite poisoning.

2.2.3 Links of Nitrate and Nitrite to Cancer Concerns and Others

The main concern of high concentrations of nitrite and nitrate in bacon is the formation of carcinogens that may cause cancer in humans. In a rat feeding study the consumption of high concentrations of nitrite showed a statistically significant increase in malignant tumors such as lymphomas (Newberne 1979). Nitrite has been reportedly linked to childhood leukemia, brain tumors, colorectal cancer, gastric cancer, stomach cancer, and more (Peters and others 1994; Sarasua and Savitz 1994; Pobel and others 1995; Knekt and others 1999; Lijinsky 1999; Boffetta and others 2000; Larsson and others 2006). Consumption of hot dogs, is a major processed meat, has been the focus of much debate for risk of cancer because of the high consumption volume, which in turn caused consumers to be more concerned about a variety of other cured meat products. Although there seems to be a correlation between nitrites and an increased risk of cancer, there are additional factors that can explain this relationship. Factors such as limited research design in reported studies, individual’s lifestyle such as smoking and drinking history, diet, and environmental surroundings are important and may need to be considered when making such an assumption. Most epidemiology studies that reported these results were not conclusive and were inconsistent.

Nitrosamine formation is one of the main concerns for carcinogenic compounds reported to occur as a result of consumption of nitrites and nitrates in cured meats, particularly bacon products (Wolff and Wasserman 1972; Lijinsky 1973; Shirley 1975; Vermeer and others 1998; Lijinsky 1999). Nitrosamines have been shown to cause cancer in humans. Fried bacon has been shown to result in the production of N-nitroso compounds such as N-nitrosodimethylamine, N-nitrosopyrrolidine, and N-nitrosothiazolidine which can be detrimental to human health (Cassens and others 1978; Miller and others 1989; Preston-martin and Lijinsky 1994; Lijinsky 1999; Liu and others 2002). Nitrosamines form from available secondary amines (such as proline and thiazolidinecaboxylic acid) reacting with nitric oxide (NO), from nitrites or nitrates, in an environment with a low pH (forms nitrous acid) and high heat (Sebranek and others 1973; Shapley 1975; Cassens and others 1978; Bharucha and others 1979; Rywotycki 2002; Honikel 2008). Side bacon was shown to contain 20-81 mg/kg of free proline (Bharucha and others 1979). In cured bacon, a nitrite intermediate (N_20_3) has been reported to react with unsaturated fat at high frying temperatures releasing nitrogen oxides that can then react with free amines, forming nitrosamines. Bharucha and others (1979) concluded that cooking time and temperature has a significant effect on the amount of nitrosamines formed. The cook-out fat contained twice as much nitrosamine as the remaining portion. Fried bacon presents a greater risk because of the frying conditions that favor nitrosamine formation.

Gamma irradiation, pasteurization, NaCl, tocopherol (Vitamin E), and sodium ascorbate (Vitamin C) all play a role in preventing nitrosamne formation (Shirley 1975; Ames 1983; Reddy and others 1983; Ahn and others 2002). On the other hand, nitrosamine amounts increased with the use of polyphosphates and sodium nitrite (Ames 1983; Kilic and others 2002). Ahn and others (2002) found that at least 20 kGy of irradiation was needed to reduce nitrosamines in sausages. Irradiation was more effective in reducing nitrosamine formation in vacuum than aerobically packaged sausages. For bacon, at least 30 kGy of irradiation is needed to reduce nitrosamine formation. However, irradiation at those levels is likely to cause a change in product flavor. Bharucha and others (1979) suggested that a good ingredient or compound inhibitor of nitrosamines needs to have the following properties; the ability to trap NO radicals, be lipophilic, not highly volatile, and heat stable up to 174^{o}C.

Nitrosamines can also be formed from nitrogen oxides found in atmospheric pollutants (Iqbal and others 1980). Other harmful compounds such as heterocyclic amines are produced upon cooking bacon and sausages at high temperatures. Polyaromatic hydrocarbons can also be produced from charcoal broiling (Sarasua and Savitz 1994). Even though nitrate and nitrates are the main focus for many researchers, there are other means by which nitrosamines can be produced. Other harmful carcinogenic compounds may be responsible besides nitrosamine.

Nitrate has relatively low toxicity compared to nitrites (Magee 1982). However, one gram of sodium nitrite has been shown to be lethal to humans (Cassens and others 1978; Tarté 2009). The consumption of nitrites and nitrates can lead to methemoglobinemia in humans, thus causing death (Wolff and Wasserman 1972; Magee 1982). Nitrites and nitrates, in high enough concentrations, will absorb the available oxygen in the body by reacting with hemoglobin and decrease oxygen availability to humans. Since nitrate is usually eliminated in the urine and the average half-life is about 5 hours, nitrate is not a major concern (Cassens 1997). The concern is when nitrate is reduced to nitrite, producing toxicity in high concentrations. To alleviate the possibility of accidental high levels of nitrite in cured meats, “Curing salts,” “Curing blends,” or “Prague Powder” is used in industry. The mixture of salt (93.75%) and nitrite (6.25%) with a pink coloring agent can help prevent unintentional usage of nitrites (Tarté 2009). Nitrates have also been restricted in use for processed meat products such as bacon (USDA, 1995).

Residual nitrite along with nitrate concentration decreases over storage time of cured meats (Sebranek and others 1973). The rate of decrease is inhibited by the increase in pH and heating of the meat product (Kilic and others 2002; Honikel 2008). Kilic and others (2002) found that the use of sodium tripolyphosphate in wiener products resulted in higher residual nitrite, but it could have been from the increase in pH observed. The decrease in residual nitrite over time is due to its reaction with muscle pigment and other proteins found in meat (Woolford and others 1976). Sodium ascorbate has been shown to accelerate the decrease in residual nitrate and nitrite observed (Honikel 2008). Nitrite from cured meat has not been established as a major cause of cancer in humans. Relative to the danger of nitrosamines, the benefits of nitrates and nitrites far outweigh the virtually negligible risk of carcinogen ingestion.

2.2.4 Nitrate, Nitrite and Potential Benefits to Humans

Nitrite has been shown to be beneficial in humans. It has been reported to help with the cardiovascular systems in humans (Shirley 1975). Nitrites have been used as a vasodilation agent to treat hypertension and to treat cyanide poisoning (Wolff and Wasserman 1972). Nitric oxide acts as an intermediate compound that can be formed from nitrite in the human body. It functions in neurotransmission, blood clotting, blood pressure control, and the immune system (Cassens 1997). Nitrite in meat is present in too low “concentrations” to impart significant physiological effects and the main benefit of nitrite in meat products is protection from food-borne pathogens that can contaminate the food consumed by consumers.

2.3 USDA Regulations for Nitrite Levels in Bacon

USDA regulations strictly control the usage of ingoing nitrate and nitrite in cured meats. Bacon requires a minimum of120 ppm of ingoing nitrite with the addition of 550 ppm of sodium ascorbate, a reducing agent. Nitrate cannot be used in the manufacture of bacon in the United States unless it is a immersion cured product (Tarté 2009). The main purpose is to ensure the safety of the consumer by very careful control of residual nitrite concentration. The regulations were modified and usage levels were reduced for bacon in response to the concern of carcinogens in the late 1960's to early 1970's.

2.3.1 Definitions of Natural/Uncured and Organic Meat Products

USDA has specific guidelines for labeling of natural, uncured, and organic processed meat. According to the 2005 USDA Food Standards and Labeling Policy Book (USDA, 2005) a natural meat product cannot contain any artificial or synthetic ingredients. Sodium or potassium nitrite or nitrate is not allowed in "natural" or organic meat products as defined in 21 CFR 101.22 because "preservative" are not permitted (Bacus 2007). In addition a "natural" meat product is minimally processed (Bacus 2007). The natural label only specifies ingredients and not the meat source. However, uncured products are allowed to contain a variety of additives and undergo other processing methods according to the Code of Federal Regulations (2006), 9 CFR 319.2 since those products fall under another category (Sebranek and Bacus 2007). A natural product may be uncured, but an uncured product does not have to meet the USDA regulations for a natural product.

The National Organic Standards Board, created by the Organic Foods Production Act, established the National Organic Program Standards in 2002 and regulates organic products. (Bacus 2007) Organic products cannot contain any sodium or potassium nitrite or nitrate or other preservatives and may be labeled in one of three ways; 100% organic, organic, or made with organic ingredients. Meat products with less than 70% organic ingredients do not qualify as an organic product. A product categorized as “100% organic” contains only organic ingredients, “organic” products contain at least 95% organic ingredients, while “made with organic ingredients” products are products with at least 70% organic ingredients. Only “100% organic” and “organic” products are allowed to have the USDA organic seal. “Made with organic ingredients” products do not qualify for the seal (Sebranek and Bacus 2007; Bacus 2007).

USDA regulations have not clearly defined what qualifies as a natural or uncured product, while organic products have been better developed. According to Sebranek and Bacus (2007) regulations for labeling of natural and uncured products needs to be improved to help consumers make an informed decision. Labeling of indirectly cured products may be misleading and confusing to consumers. Sebranek and Bacus (2007) recommended that a new category of cured products be identified. It was suggested that indirectly cured products be labeled with terms such as “Naturally preserved with” or “Naturally cured with” to help consumers identify meat products cured naturally (Bacus 2007). USDA is still working on regulations and has not made a final ruling on these new products. Until better regulations are in place, labeling of natural and uncured meat products may be confusing for consumers.

2.4 Traditional and Natural Curing Process

A traditional meat curing process for bacon typically contains a solution of water, salt, a reducing agent, and nitrite or nitrate which is injected into the raw pork belly. Sodium erythorbate (reducing agent and isomer of ascorbate) is not a critical factor for product acceptability with nitrite but provides for faster curing reactions. However, at low levels of nitrite, below 52ppm, it has been shown to effect color, flavor, and overall acceptability of frankfurters (Sebranek and others 1977). Most cured meats are then heat treated (with smoke to a pasteurizing temperature) and vacuum packaged. The cured meat product is then considered ready-to-eat and safe to consume for several weeks with proper refrigeration. However, bacon is typically heat processed to only 55^{o}C-56^{o}C because it is cooked before consumption.

According to Sindelar and others (2007a) common ingredients found in natural and uncured processed meat products include; sea salt, evaporated cane juice, raw sugar, turbinado sugar, lactic acid starter culture, natural spices, natural flavorings, celery juice, and celery juice concentrates. Similar ingredients were found in organic processed meat products. However, they were organic ingredients. The celery juice or concentrate provides a source of nitrate that is a natural component of vegetable juice. The starter culture reduces nitrate to nitrite. The rest of the process is then similar to sodium nitrite being added directly to a traditionally cured meat product. Examples of starter cultures that can be used include *Kocuria varians*, *Staphylococcus xylosus*, *Staphylococcus carnosus*, and others (Sebranek and Bacus 2007). Sindelar and others (2007b, 2007c) showed that vegetable concentrates are an effective source of nitrate for naturally curing meat products as long as adequate incubation time for the culture and sufficient concentration of vegetable juice powders were used.

Other technologies and methods are available that affect or help to ensure that safe, good quality cured meat products are being produced. High pressure processing, irradiation, animal diet supplements, controlling belly thickness for bacon, and other alternative ingredients to provide some of the functions of nitrite and nitrates may be utilized. Irradiation can improve the shelf life of bacon along with ensuring the reduction of nitrosamines. Vitamin E supplementation in the diets of pigs has shown to help reduce oxidative rancidity. However, in coarsely ground cured sausage and pork roast, the addition of tocopherol showed no effect in lipid oxidation when the products were stored frozen. It is important to note that treatment with 1000 mg/kg of tocopherol slowed off-flavors until week 37 (Channon and Trout 2002). Belly thickness also affects consumer acceptability and slicing yields (Person and others 2005). Thin bellies (~2.0cm) produced bacon that lacked crispness with low slicing yields. On the other hand, thick bellies (~3.0cm) did not have enough flavor, but had high slicing yields. Consumers preferred bacon from thin and average (~2.5cm) bellies. Organic acid salts, such as sodium lactate and sodium acetate, have also shown to be effective in inhibiting pathogens such as *Clostridium* and *Listeria monocytogenes* (Juneja and Thippareddi 2004; Geornaras and others 2006). Lactate use is limited to 0.25% by weight as a flavor enhancer while 0.25 to 4.8% is allowed as a microbial inhibitor. Using a combination of nitrite with potassium sorbate can also reduce nitrite usage. However, the sorbate-cured bacon resulted in higher TBA values that could have resulted from sorbate reacting with the TBA reagent. An increase in pH and lower cured color conversion for bacon with sorbate was also observed (Amundson and others 1982a; Amundson and others 1982b). Thus, there are many alternatives available for processors. However, choosing the right one may be difficult.

In many natural and uncured meat products today, vegetable juice powder is utilized as the source of nitrate. The nitrate is then reduced by the starter culture to nitrite which, in turn develop similar cured characteristics as a traditionally cured meat product. Vegetables such as beets, celery, and lettuce contain high levels of nitrate. Celery is commonly used because it has relatively little effect on meat product flavor and color development. Even though beets may contain a higher concentration of nitrate, beet extracts and concentrates impart a reddish-purple color to the product.

2.5 Quality Concerns of Natural/Uncured, Organic Bacon

Variation in bacon quality can negatively affect the industry because it only takes one bad experience to discourage a particular consumer from repeat purchases. Consumers have other protein alternatives such as poultry, beef, and plant sources that are growing in availability. There are many factors that affect the quality attributes of pork products. Pork meat can be poor in quality from PSE (pale, soft, exudative), RSE (red soft, exudative), and DFD (dark, firm, and dry) meat. It has been shown that PSE and DFD pork loins for example are unacceptable to consumers (Topel and others 1976). PSE, which was identified in the 1960’s, is still a major issue of concern in pork quality and can result in poor quality processed meat products. In the USA 18% of pork was found to be PSE in 2000, an increase from 16% since 1992 (Cassens 2000). The issue has been addressed through the recognition of PSS (porcine, stress, syndrome) susceptible pigs, genetic breed selection, diets, through animal welfare/handling improvements, and other techniques. High amounts of unsaturated fat can result in soft bellies, causing sliceability issues. In contrast, bacon that is high in saturated fat can result in shattered bacon (Teye and others 2006). The age of the animal can also affect tenderness of the product. Bacon from carcasses 36-42 month old was less tender when compared to younger hogs (Carpenter and others 1963).

Natural and uncured bacon can be manufactured in two ways methods. One method is simply with no addition of nitrate or nitrate. The second method is indirect curing through a nitrate source and starter culture. The addition of starter culture to reduce nitrate to nitrate may introduce a variable amount of cure or ingoing nitrite seen between different batches of meat produced if not carefully controlled. Residual nitrite levels can then be variable, causing another area of concern. Processors now have the option of buying pre-converted nitrate-to-nitrite vegetable powder for their meat products. The pre-converted powder is essentially a direct addition of sodium nitrite to the product, but still qualifies as a natural ingredient because it is from a natural source. Products without any nitrite or nitrate exhibit extremely poor quality and no cured product properties similar to that which consumers expect in cured bacon. Organic bacon on the other hand can only use organic ingredients, but can utilize the "natural" curing process with vegetable ingredients that provide nitrate and/or nitrite. Natural, uncured, and organic bacon quality is likely to be different compared to commercially available traditionally cured brands of bacon (Sindelar and others 2007a).

A study by Wright and others (2005) found that most bacon brands found in retail were similar in most quality characteristics and palatability traits between store brands, low-priced national brands, and high-priced national brands (n=200). However, there was also wide variability in quality characteristics. Sindelar and others (2007a) did preliminary work in this area, comparing commercial no nitrate/nitrite hams, bacons, and frankfurters. There was a large variation found between brands and between replications for all product categories. For bacon, one of the uncured brands was considered unacceptable by sensory panels compared to the control brand in this study, and was scored lowest for lean color, aroma, flavor, texture, and overall acceptance. There were differences between a* (redness) color, reflectance ratios, total pigment, cured pigment, and TBARS values (Sindelar and others 2007a). From this initial study on commercial hams, bacons, and frankfurters, variation in attributes particularly for natural and organic products being produced on the market have been observed. Sindelar then conducted further studies with hams and sausages to investigate processing conditions that may help produce natural and organic products with similar attributes as traditionally cured.

In a study with naturally cured hams, Sindelar and others (2007b) found that a level of 0.35% vegetable juice powder allowed trained sensory panelists to detect a vegetable aroma and flavor regardless of the incubation time. When 0.20% vegetable juice powder treatment was compared to the traditionally cured ham treatment, evaluation of sensory and product attributes resulted in no difference. Measurement of preincubation and postincubation nitrate levels showed that the starter culture was effective in converting nitrate in the vegetable juice powder to nitrite. Residual nitrite levels then decreased over time for all treatments. Sindelar's study concluded that the incubation time was not important in hams, probably due to the effect of product diameter. A large diameter product requires longer heating time, essentially providing the necessary incubation of the starter, thus an increase in incubation time does not matter when indirectly curing ham (Sindelar and others 2007c).

Sindelar and others (2007c) found that there was no difference in sensory attributes detected in producing uncured small diameter sausages with vegetable juice powder and starter culture *Staphylococcus carnosus*. The control group had a higher score for cured color, flavor, and was found to have a more firm texture. In this case, the incubation time was found to be more important than the amount of vegetable juice powder utilized. Incubation of the vegetable juice powder for 120 minutes resulted in product properties more similar to traditionally cured sausage than an incubation time of 30 minutes. No differences in TBARS values were observed. Longer incubation time and higher vegetable juice powder concentration resulted in a significantly higher residual nitrite concentration when compared to the control treatment. One concern was that the lower ingoing levels of nitrite may present a microbiological concern for *C. botulinum* survival and outgrowth because nitrite has been shown to provide a protective effect (Sindelar and others 2007b). From these two studies uncured hams and sausages require two different approaches when using vegetable juice powder and starter culture to naturally cure meat products with high quality.

With increased consumer concern about their health, the composition of pork and processing conditions has changed over the years. Hogs are now leaner. The increased consumer awareness about the amount of calories, fat, salt content, and ingredients included in their processed meat products have resulted in new hurdles and technologies. With more competition in the market, production of high quality products has become more crucial. As companies are moving forward, these processes need to be validated to ensure that high quality and taste is maintained while still being safe to consume.

2.6 Safety Concerns of Natural, Uncured, and Organic Bacon

There is a concern for the safety of natural, uncured, and organic products being produced in the market. Organic products are especially of a concern due to the possible higher microbial load found from being raised antibiotic free (Heuer and others 2001; Sofos 2008). This causes a concern for consumer safety. Research is needed to validate the safety of these products. In contrast, the indirect addition of nitrate through vegetable juice powder in nonorganic and organic products may introduce lower levels of ingoing nitrite and induce variability from batch to batch, also causing safety concerns.

Previous research has shown that residual nitrite inhibits *C. botulinum*, though the toxin has been shown to be inhibited by other means as well. Alternatives to nitrite are available and may help ensure safety of processed meat from *C. botulinum*. In bologna 0.56% of potassium sorbate has shown to be as effective as sodium nitrite for *C. botulinum* control. In bacon, similar quality characteristics were observed for bacon with potassium sorbate and reduced nitrite compared with traditionally cured bacon, but some pH and color issues were observed (Amundson and others 1982b). However, a lactic acid starter culture was found to be most effective overall as a protective measure against *C. botulinum*. Lactic acid can affect flavor of some processed products that are basic or neutral in pH, but may be ideal in bacon processing (Chang and others 1983). Other treatments that may be used to improve safety include thermal processes, nonthermal processes, packaging, low pH, high salt content, low water activity, and other natural antimicrobial additives. New technologies such as utilization of high hydrostatic pressure, electroporation with pulsed electric fields, bacteriophages, smart antimicrobial packaging, and edible antimicrobial films may also be effective (Sofos 2008).

The new bacon products represent a concern for food borne illnesses of microbiological origin if alternative curing processes for bacon without any direct nitrite or nitrate are not validated.

2.7 Summary of Literature Review

As consumers demand new products with cleaner and healthier labels, it is becoming a challenge for processors to produce satisfying, high quality, and safe bacon products. Nitrite has been used to provide cured flavor, color, antioxidant, and antimicrobial properties in cured meats including bacon. Because natural and organic labeled bacon cannot utilize direct addition of nitrate or nitrite, this requires that alternative methods to be used. Finding an alternative to nitrite with all of its functional properties is difficult and the processes currently being used are variable and may result in more or less nitrite than would be ideal. As processors are investigating different alternatives in producing natural, uncured, and organic bacon, standards of production need to be established to ensure that consistent quality of bacon is being produced.

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CHAPTER 3. QUALITATIVE CHEMICAL MEASURES TO INDIRECTLY ASSESS QUALITY OF NATURAL, ORGANIC BACON COMPARED TO TRADITIONALLY CURED BACON.

A paper to be submitted to the Journal of Food Science

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3.1 Abstract

A total of 12 commercial brands of bacon were analyzed for color, total pigment (TP), cured pigment concentration (CP), % cured color (PCP), water activity (a_w), TBARS, pH, salt content (NaCl), residual nitrite (NO2), moisture, fat, and protein. Moisture was found to be different and higher between the overall means of the control (traditionally cured) versus the natural/uncured group ($p<0.05$). When comparing the control (traditionally cured) to the organic group, a*, b* value of obliquus abdominis internus/externus muscle, percent cured color, TBARS, moisture, and fat were found to be different ($p<0.05$). The a*, b*, PCP, and moisture values were lower while TBARS and fat were higher. Comparing means between individual brands resulted in color scores, cured pigment, % cured color, TBARS, salt content, residual nitrite, moisture, and fat that were different between the brands of bacon ($p<0.05$). Two brands of commercial bacon indicated off-flavors and lipid oxidation. A positive correlation was found between residual nitrite and pH levels. In contrast, a negative correlation for L* value of the obliquus abdominis internus/externus muscle was found with residual nitrite levels. In a preliminary inoculation study, there was no correlation between residual nitrite and inhibition of *Clostridium perfringens*. There was a correlation between water activity and salt levels to *C. perfringens* at p-value<0.10. Variation in a*, b* color values (for obliquus abdomis internus/externus muscle), CP, PCP, TBARS,

$NaCl$, NO_2, moisture, and fat characteristics was found between commercial bacon brands, causing concern for quality and safety of emerging bacon categories.

3.2 Introduction

Increased supply of natural, uncured, and organic bacon in the market has led to increased concern for quality and safety of bacon manufactured with no direct addition of nitrite or nitrate compared to traditionally cured bacon. Traditionally cured bacon has been proven to be a consistently high quality product that is safe when cured by conventional methods (Sebranek and Bacus 2007). As more processors are entering the market for natural and organic processed meats with little or no guidelines available for production of naturally cured, uncured, or organic bacon, variability in chemical properties and quality characteristics of these products have become a concern. Inconsistent quality can affect future consumption of these emerging bacon products and could compromise safety. An assessment of the products currently on the market is needed to help provide a better understanding of the current situation and what factors may impact quality and safety. Processors need to be able to provide consistent quality natural or organic bacon and to ensure that consumers are receiving a product similar to that of traditionally-cured bacon.

The traditional meat curing process for bacon typically includes a brine solution of water, salt, a reducing agent, and the addition of nitrite or nitrate that is injected into raw pork bellies. The meat is then heat treated usually with smoke, chilled, sliced, and vacuum packaged. The key ingredient in traditionally cured meat products is nitrite or nitrate (Cassens 1997). Sodium nitrite has been used since Roman times (~3000 B.C.) as a method to cure and preserve food (Pegg & Shahidi, 2000). Although sea salt was first believed to be the main curing ingredient for preservation, it is believed that crude salt was contaminated with nitrate (salt peter or potassium nitrate) which subsequently led to direct use of nitrate for meat curing (Cassens and others 1978; Honikel 2008). More recently nitrite has been shown to be the essential active component in meat curing after it reduction from nitrate by bacterial reduction. Today, nitrite is recognized as responsible for cured flavor, color development, antioxidant activity, and antimicrobial protection, ensuring the quality and safety that consumers expect of cured meats (Wolff and Wasserman 1972; Honikel 2008). Nitrite has also been shown to extend product shelf life through its functional properties as an antioxidant and antimicrobial.

There are two approaches used for producing natural, uncured, and organic processed meat products that resemble traditionally cured products. These processed meat products may be produced either with no added nitrate or nitrite, or by adding nitrate or nitrite indirectly with proper labeling in each case (Sindelar and others 2007a). Without the addition of any nitrate or nitrite, the properties that consumers expect of cured meat will be absent. Addition of nitrate from natural sources such as vegetables is considered indirect addition of curing agents and requires an incubation step to allow sufficient time for the conversion of nitrate to nitrite by the use of a starter culture. Starter cultures such as *Kocuria varians*, *Staphylococcus xylosus*, and *Staphylococcus carnosus* may be used (Sebranek and Bacus 2007). If standardized incubation times and nitrate concentration in the vegetable source ingredient are not consistent, variability in the properties of the resulting product are likely. Sindelar and others (2007b,c) showed that incubation time was important in small diameter sausages but not in ham, where the large product size requires a relatively long heat process that essentially provides adequate incubation time. Most commercial brands of natural and organic processed meat that resemble conventionally cured products use vegetable juice powder (such as celery) as a source of nitrate for the cure. Celery has the benefit of containing high levels of nitrate, in addition to having minimal effect on flavor and color. Meat processors also now have the option of using vegetable sources where the nitrate has been commercially pre-converted to nitrite. Currently, regulations on use of natural ingredients are being updated by the USDA. A final ruling has not yet been issued.

However, USDA has specific guidelines to what manufacturers can label as natural, uncured, or organic meat products. According to the 2005 USDA Food Standards and Labeling Policy Book (USDA, 2005) a meat product labeled as “natural” cannot contain any preservatives, or artificial ingredients. Sodium or potassium nitrite or nitrate is not allowed in “natural” or organic meat products as defined in 21 CFR 101.22 because these compounds are considered preservatives (Bacus 2007). In addition, a “natural” meat product must be only minimally processed (Bacus 2007). The natural label only specifies ingredients, but not the meat source since meat is considered natural in the native, raw state. However, products that are truly uncured (no nitrate or nitrite) are allowed to contain other additives and processes, that are not allowed in products labeled as natural according to the Code of Federal Regulations (2006), 9 CFR 319.2 (Sebranek and Bacus 2007). Thus, a product labeled as natural is also labeled as uncured (even if natural sources of nitrate and nitrite are included), but an uncured product such as pork sausage, for example does not necessarily have to meet the USDA regulations for a natural product.

The National Organic Standards Board established the National Organic Program Standards in 2002 as a result of the Organic Foods Production Act, regulates the production and labeling of organic products. Organic foods fall into one of three categories for labeling;

“100% organic”, “organic”, and “made with organic ingredients”. Products with less than 70% organic ingredients do not qualify as an organic product. A “100% organic” product contains only organic ingredients, “organic” products contains at least 95% organic ingredients, while “made with organic ingredients” products are products with at least 70% organic ingredients. Only “100% organic” and “organic” products are allowed to include the USDA organic seal on the label. Products “made with organic ingredients” are not allowed to use the seal (Sebranek and Bacus 2007; Bacus 2007).

USDA regulations have not provided a final ruling as to what qualifies as a natural or uncured product while organic products have been much better defined. According to Sebranek and Bacus (2007) regulations for labeling natural and uncured processed meat products need to be improved in order for consumers to make informed decisions. Current labeling of indirectly cured products (natural, uncured) may be misleading and confusing to consumers. Sebranek and Bacus (2007) recommended that these cured products be labeled with terms such as “Naturally preserved with” or “Naturally cured with” to help consumers identify meat products cured with natural ingredients. Until better regulations are in place, labeling of natural and uncured meat products may remain confusing to consumers.

Due to the increased interest by consumers in the United States, the meat industry is experiencing a consumer emphasis on nutrition and health and has responded with efforts to produce high quality meat products with assured food safety (Vandendriessche 2008; Cassens 1997). There continues to be an ongoing debate on the consumption of nitrite and nitrate from cured meats and potential links to carcinogenic compounds such as nitrosamines. Nitrite has been linked to childhood leukemia, brain tumors, colorectal, gastric, stomach cancer, and more (Peters and others 1994; Sarasua and Savitz 1994; Pobel and others 1995;

Knekt and others 1999; Lijinsky 1999; Boffetta and others 2000; Larsson and others 2006). Many ingredients, including nitrite and salt have been the target of negative implications for health and are therefore slowly being reduced by the industry or, in some cases, eliminated. Because salt reduces available water for bacterial growth, the inhibition of many pathogens such as *Clostridium botulinum,* is likely to decrease. Similarly, when salt concentration is reduced, a change in the amount of nitrite utilized by indirect addition of nitrite with nonvalidated methods may alter not only quality, but also safety of the meat products processed with these methods. American consumers are focused more on their diets today than on improving their physically inactive lifestyle. As consumers are searching for more diet options, processors need to become more aware and be able to address these issues with alternative technologies and ingredients while still providing expected product quality and safety.

The objective of this study was to determine if variations in quality of natural/uncured and organic bacon exist relative to conventionally cured bacon and consider any safety implications suggested by product variation.

3.3 Materials and Methods

Experimental Design

To assess the quality of natural, organic and uncured bacon, 12 commercial brands of bacon were analyzed. This included nine products labeled as natural/uncured, two labeled as organic, and one traditionally-cured bacon sample to serve as a control. The commercial brands were randomly chosen from those commercially available in central Iowa. Three replications with different sell-by dates for each product were analyzed. Each brand was given a letter designation (AB-LB). Table 2 identifies each brand as natural/uncured, organic, or traditionally cured, and Table 3 lists the ingredient statement for each brand. Looking at the ingredient statement brands IB, HB, and LB appear to be “truly uncured” brands of bacon with no vegetable juice/concentrate or starter culture. The *Clostridium perfringens* study was conducted in parallel by Jackson 2009.

Commercial bacon samples were purchased from retail stores in central Iowa and transported to the Iowa State University Meat Laboratory (Ames, IA, U.S.A.). Analysis of each replication with the same sell by date included two packages of each sample and analytical measures used for the sample mean. Because of relatively small package size, two brands of bacon (AB, GB) were analyzed using four packages of each for replicates two and three to ensure sufficient sample quantity for analysis. Three of the brands of bacon were displayed as frozen products on store shelves. Frozen brands were opened and allowed to temper in the refrigerator overnight. Bacon packages were opened on the day of analysis and objective color values (Hunter L*, a*, b*), total pigment, cured pigment, percent cured color, water activity, TBARS value, pH, salt, residual nitrite, crude fat, moisture, and protein were measured following procedures as described by Sindelar and others (2007a).

Color Value Measurements

Objective color values were measured using a Hunterlab Labscan Spectrocolorimeter (Hunter Associated Laboratories, Inc., Reston, Va., U.S.A.). Measurements were taken for the obliquus abdominis internus/externus (darker color lean muscle, but could likely be one of several other muscles including; triceps brachii, subscapularis, seratus ventralis, latissimus dorsi, intercostales externi, diaphragm, and rectus abdominis) and cutaneous trunci muscle

Table 2. Bacon treatment identification.

ID: Code	Direct Nitrite	Naturally Cured*	Antimicrobials
Control:			
JB	Yes	No	sodium nitrite
Natural/Uncured:			
AB	No	Yes	No
CB	No	Yes	No
BB	No	Yes	No
DB	No	Yes	No
EB	No	Yes	Lactate
FB	No	Yes	No
KB	No	Yes	No
IB	No	No**	No
HB	No	No**	No
Organic:			
LB	No	No	No
GB	No	Yes	No

*Naturally cured was identified by ingredient statements that include lactic acid starter culture
**These brands were truly uncured (no forms of nitrite added)

Table 3. Ingredient statements of bacon brands analyzed

ID: Code	Ingredient statements (in addition to pork)
Control:	
JB	water, salt, sugar, dextrose, sodium erythorbate, sodium nitrite
Natural/Uncured:	
AB	water, sea salt, celery juice, evaporated cane juice, lactic acid starter culture (not from dairy)
CB	water, sea salt, cane sugar, natural flavors, lactic acid starter culture (natural fermenting agent)
BB	water, sea salt, turbinado sugar, natural spices, lactic acid starter culture
DB	water, salt, turbinado sugar, natural flavoring, lactic acid starter culture
EB	water, brown sugar, salt, sodium lactate (from corn source), celery juice concentrate, lactic acid starter culture
FB	water, salt, turbinado sugar, celery powder, lactic acid starter culture (not from milk)
KB	water, sea salt, evaporated cane juice, celery powder, lactic acid starter culture
IB	water, sea salt, evaporated cane sugar
HB	sea salt, raw sugar, spices
Organic:	
LB	untreated salt, organic evaporated cane juice, organic beet powder, organic brown sugar, organic spices
GB	water, sea salt, organic honey, celery juice, organic spices, lactic acid starter culture

(lighter color lean muscle, could also likely be pectoralis profundus), depending on where the bacon was sliced from the pork belly (Jabaay and others 1976; Jones and others 2006). The instrument settings used were illuminant A, 10^{o} standard observer, a 0.64 cm viewing area and 1.02 cm port size. Commission International d'Eclairage (CIE) L* (lightness, 100 = absolute white to 0 = absolute black), a* (positive value = redness, negative value = greenness intensity), and b* (positive value = yellowness, negative value = blueness intensity) values were recorded. Three values were recorded for each bacon package for each replication.

Total Pigment Analysis

Total pigment concentration was determined through a method of Hornsey (1956) which was modified by Sindelar (2007a). Total cured pigment samples were prepared by mixing 10 g of ground bacon, 40 ml of acetone, 2 ml of distilled, de-ionized water, and 1ml of hydrochloric acid. The sample was mixed using a Polytron Mixer (PT 10/35, Kinematical GmbH, AG, Switzerland) for 1 minute at a speed setting of 7. Total pigment sample was then filtered after 1 hour and measured at 640 nm with a spectrophotometer (A_{640}). The reading was then multiplied by 290 to arrive at the ppm of nitrosylhemochrome concentration. There was an effort throughout the whole process to expose the samples to as little light as possible.

Cured, and Percent Cured Pigment Analysis

Cured pigment concentration was determined through a method of Hornsey (1956) which was modified by Sindelar (2007a). Cured pigment samples were prepared by mixing 10 g of ground bacon samples with 40 ml of acetone and 3 ml of distilled water under as little light as possible. The sample was mixed using a Polytron Mixer (PT 10/35, Kinematical GmbH, AG, Switzerland) for 1 minute at a speed setting of 7. Cured pigment sample was measured at 540 nm right after filtering the sample to reduce any light exposure (A_{540}). The reading was then multiplied by 680 to arrive at the ppm of total pigment concentration. There was an effort throughout the whole process to expose the samples to as little light as possible. Percent cured color was calculated from total pigment and cured pigment using the formula 100 x (Cured Pigment/Total Pigment).

Water Activity Measurement

A commercial water activity meter, Pa$_w$kit (Decagon Devices, Inc., WA, USA) was used (accurate +/- 0.02 a_w). Ground bacon samples were used to fill a small Pa$_w$kit plastic sample container to 1/3 full with the edges cleaned before reading the sample. The container was first standardized with 0.76 and 0.25 a_w standards. The sample was then inserted, allowed to equilibrate, read and the water activity (a_w) value recorded.

TBARS Analysis

Zipser and Watts (1962) TBARS (2-thiobarbituric acid reactive substances) method for lipid oxidation measurement in cured meats was used. Ten grams of ground bacon sample was weighed into a round bottom flask. Solvents, antifoam, and boiling beads were then added. Following distillation, approximately 50 ml of sample was collected and transferred to a test tube. TBA reagent was then added to the distillate, lightly stirred, and allowed to boil for 35 minutes at ~100^{o}C. The test tube was cooled to room temperature submerged in cold water for 10 minutes. Sample absorbance at 532 nm was recorded and expressed as mg of malonaldehyde equivalents/kg of meat sample. A greater value indicates a greater amount of lipid oxidation in the bacon sample. According to Sindelar and others (2007c) and Tarladgis and others (1960), TBARS values of 0.5 to 1.0 are often considered to be the threshold for oxidized odor while TBARS value of 1.0 to 2.0 is the threshold for oxidized flavor.

pH Measurement

A pH/ion meter (Accumet 950: Fisher Scientific, Fair Lawn, N.J., U.S.A.) equipped with a glass electrode (Accumet Flat Surface Epoxy body Ag/AgCl combination Electrode Model 13-620-289, Fisher Scientific, Fair Lawn, N.J., U.S.A.) was utilized. The pH meter was calibrated before use with pH 4.0 and pH 7.0 Fisher Scientific buffer solutions. For each package, duplicate measurements were made. Ten grams of ground bacon was mixed with 90 ml of distilled water, then mixed with a Polytron (PT 10/35, Kinematica GmbH, AG, Switzerland) for 45 seconds at speed 7. After mixing, the samples were filtered and measured with the calibrated pH meter.

Salt Analysis

Salt analysis was conducted using a Quantab Commercial Kit (Quantab Chloride Titrator, Environmental Test Systems, Inc., Elkhart, IN, U.S.A.). Ten grams of ground bacon was weighed into a beaker with 90 ml of boiling, distilled water. The solution was then mixed using a glass rod for 1 minute, allowed to rest for 30 seconds, and stirred again for one minute. The sample was then allowed to cool to room temperature. Whatman No. 1 filter paper was then inserted into the beaker. A Quantab indicator strip was inserted into the distillate and, following the change in color of the indicator strip, the salt content was read and recorded. The percentage of sodium chloride in the sample was calculated based on the chloride ion concentration indicated on the strip.

Residual Nitrite Analysis

Residual nitrite was measured using AOAC the colorimetric method (AOAC, 1990b) with 10 g of sample weighed into a 500 ml volumetric flask. The flask was then 2/3 filled with hot, distilled, de-ionized water and capped. The flask was inserted into a fume hood on a steam bath for 2 hours. At 30 minute intervals, samples were swirled. The flask was then cooled for 2 hours at room temperature. The sample was then filtered through Whatman No. 1 filter paper, transferred to a 50 ml volumetric flask, then 2.5 ml of sulfanilamide reagent and 2.5 ml of NED (N-(1-naphthyl)ethylenediamine-2-HCL with 15% acetic acid) reagent were added to the distillate. After color development in the samples, the absorbance was read at 540 nm with the spectrophotometer. The nitrite concentration was then calculated from a standard curve of known nitrite concentrations.

Crude Fat, Moisture, and Protein Analysis

AOAC methods were used for the proximate analysis of bacon samples. Crude fat (AOAC 1990), moisture (AOAC 1990a), and crude protein (AOAC 1993) were obtained for each package in each replication. Moisture was determined by drying the sample in an oven at 100-102 ºC and recording the difference in weight. Crude fat was determined by petroleum ether extraction. A TruSpec®N combustion instrument was utilized to measure crude protein.

Statistical Analysis

Three independent replications of commercial bacon were evaluated for the study. Data was analyzed through PROC GLM (general linear models) using F-test and LSM (least square means) procedure of the Statistical Analysis System software program (SAS version 9.1, SAS Institute Inc., Cary, N.C., U.S.A.). The F-test confirmed if significant attribute differences were present between the control relative to natural/uncured bacon samples, and the control relative to organic bacon samples. Pairwise comparisons were made between brands with Tukey Kramer procedure and were used to adjust for multiple comparison of means. One-way Multivariate analysis (MANOVA) was performed to confirm any partial correlation between bacon characteristics. In addition, a partial correlation table between bacon characteristics and the growth of *Clostridium perfringens* was established as a potential predictor for *Clostridium botulinum* concerns (Jackson 2009). Significance was determined with a $p<0.05$ level.

3.4 Results and Discussion

Data means and standard deviations were calculated between replications. Moisture was found to be different and higher between the overall means of the control (traditionally cured) versus the natural/uncured group ($p<0.05$). Results showed that the difference between the addition of nitrite and natural/uncured meat was very minimal (Table 4). This indicates that the natural/uncured group is similar in physiochemical properties to traditionally cured bacon. When comparing the overall means of the control (traditionally cured) to organic labeled bacon group, a*, b* value of obliquus abdominis internus/externus muscle, percent cured color, TBARS, moisture, and fat were different between the two categories ($p<0.05$) (Table 4). The a*, b*, PCP, and moisture values were lower while TBARS and fat were higher. The measured differences in color and lipid oxidation between control (nitrite added) and organic labeled bacon suggest variability in physiochemical properties and likely quality differences. Surprisingly, residual nitrite was not statistically significant between the control (nitrite added) versus natural/uncured or organic labeled bacon. The low residual nitrite may have been affected by when the product was taken from the market. Residual nitrite has been known to decrease over time. A trend ($p<0.10$) for a difference in amount of residual nitrite between control (nitrite added) and the organic labeled bacon may exist. Only two brands of organic bacon were analyzed. This indicates other factors, besides residual nitrite, may influence bacon quality. However, due to the small quantities of residual nitrite found between the groups, it may have affected its role in determining bacon quality.

Statistical analysis was performed through pairwise comparison, and found an increase in physiochemical differences when comparing brands individually to the control ($p<0.05$). Because bacon is highly variable in composition, especially in moisture and fat, comparing each brand separately may deem more beneficial. The attributes that were found to be similar between the 12 commercial brands of bacon were the L* values for both cutaneous trunci and obliquus abdominis internus/externus muscle, a* and b* values of the cutaneous trunci muscle, total pigment, a_w, pH, and protein content. These attributes are consistent between brands and therefore, similar in quality. The results found that a* and b* in the obliquus abdominis internus/externus muscle, cured pigment, percent cured pigment, 2-thiobarbituric acid reactive substances, salt, residual nitrite, moisture, and fat attributes to be different between control and each other brand (Table 5 and 6).

Objective Color Measurement, Total, Cured, and Percent Cured Pigment

The SAS analysis performed in conjunction with pairwise comparison of brands showed that a* and b* value for the obliquus abdominis internus/externus lean muscle was different between control and each other brand ($p<0.05$) (Table 5). From these results, variability in color exists. The color differences seen in the darker muscle, could be due to measurements taken from different muscles besides obliquus abdominis internus/externus. This could depend on where the bacon was sliced on the pork belly. Different muscles are predominant between the anterior (shoulder) to posterior (flank) portion of the pork belly. The brand means for a* was found to be different and lower between one organic brand (LB) and control (JB). The brand means for b* showed that one natural/uncured (FB) and one

Table 4. Significance of overall means between control vs. natural/uncured and control vs. organic labeled bacon.

	p-values between overall means								
	Obliquus abdominis								
Comparison	a*	b*	CP	PCP	TBARS	NaCl	N02	Moisture	Fat
Attribute p-value	*0.0122*	*0.0003*	*0.0009*	*0.0026*	*<0.0001*	*0.0027*	*0.0002*	*0.0024*	*0.0145*
Control vs. natural/uncured and organic	nsp	0.0187	nsp	nsp	0.0985*	nsp	nsp	0.0146	0.0288
Control vs. natural/uncured	nsp	0.0511*	nsp	nsp	nsp	nsp	nsp	0.0467	nsp
Control vs. organic	0.0334	0.0011	nsp	0.0733*	<0.0001	nsp	0.0638*	0.0005	0.0012

P<0.05, *P<0.10, trend to be significant, nsp – not significant p-value

a* - redness to greenness intensity, b* - yellowness to blueness intensity, CP – Cured pigment, PCP – Percent cured pigment, TBARS – 2-thiobarbituric acid reactive substances, NaCl – salt, N02 – residual nitrite

Table 5. Physiochemical Analysis Average color measurements in traditionally-cured (control), natural and organic bacon.

	Hunter color meter						Pigment Concentration		
	Obliquus abdominis			Cutaneous trunci			TP	CP[1]	PCP[1]
ID: Code	L*	a*[1]	b*[1]	L*	a*	b*	(ppm)	(ppm)	%
p-value	*0.1783*	*0.0122*	*0.0003*	*0.7819*	*0.6428*	*0.1968*	*0.7504*	*0.0009*	*0.0026*
Control:									
JB	40.94	8.85^{bc}	5.25^{c}	52.83	3.87	2.35	63.85	40.07^{bcd}	63.17^{ab}
(Std. Dev.)	*2.86*	*0.93*	*0.25*	*4.70*	*0.66*	*0.97*	*11.86*	*6.43*	*5.12*
Natural / Uncured									
AB	42.83	8.27^{c}	5.84^{c}	56.22	2.11	3.24	73.24	31.38^{d}	43.24^{cd}
(Std. Dev.)	*3.03*	*0.61*	*1.22*	*4.09*	*0.45*	*0.72*	*11.22*	*3.53*	*5.55*
CB	42.97	9.40^{ab}	6.33^{bc}	52.05	5.13	4.19	68.63	39.58^{bcd}	58.44^{abc}
(Std. Dev.)	*4.54*	*4.92*	*3.63*	*1.96*	*1.76*	*0.50*	*10.79*	*3.00*	*8.93*
BB	40.99	10.11^{b}	6.88^{c}	52.78	4.14	2.74	88.21	52.77^{ab}	62.35^{ab}
(Std. Dev.)	*3.24*	*0.77*	*0.19*	*6.22*	*0.35*	*0.25*	*24.23*	*1.34*	*13.83*
DB	41.17	8.23^{bc}	6.56^{c}	53.01	3.49	3.70	68.86	44.91^{abc}	69.98^{a}
(Std. Dev.)	*2.36*	*0.78*	*1.39*	*3.60*	*0.88*	*0.44*	*21.67*	*3.49*	*22.97*
EB	41.60	7.90^{b}	3.64^{bc}	53.26	4.80	4.19	80.36	42.74^{abcd}	55.37^{abc}
(Std. Dev.)	*2.93*	*0.23*	*0.55*	*2.59*	*1.21*	*1.93*	*30.53*	*8.71*	*9.18*
FB	43.96	8.45^{b}	7.35^{ab}	55.47	4.45	5.81	74.69	38.97^{cd}	54.14^{abc}
(Std. Dev.)	*1.54*	*1.45*	*0.69*	*1.74*	*1.20*	*1.14*	*28.92*	*11.15*	*8.44*
KB	40.05	8.89^{bc}	5.82^{c}	48.02	3.60	2.44	64.65	43.19^{bcd}	67.64^{ab}
(Std. Dev.)	*6.51*	*0.78*	*0.73*	*3.84*	*0.70*	*1.15*	*10.26*	*4.85*	*6.57*
IB	45.13	9.69^{b}	6.07^{c}	58.40	4.28	3.02	62.34	40.98^{cd}	66.24^{abc}
(Std. Dev.)	*3.84*	*2.16*	*2.22*	*5.72*	*1.98*	*2.97*	*15.40*	*11.24*	*25.18*
HB	39.93	10.67^{ab}	6.12^{bc}	51.02	5.08	4.16	89.71	42.64^{abcd}	48.06^{bc}
(Std. Dev.)	*5.30*	*2.49*	*2.66*	*2.20*	*1.07*	*1.37*	*33.56*	*13.95*	*3.19*
Organic:									
LB	40.39	8.43^{a}	7.95^{a}	52.56	6.81	7.87	64.40	16.45^{e}	25.88^{d}
(Std. Dev.)	*1.05*	*0.37*	*0.40*	*2.81*	*1.81*	*0.40*	*15.17*	*2.38*	*2.39*
GB	43.67	10.36^{b}	6.94^{c}	53.52	4.27	2.79	77.05	55.95^{a}	72.5^{a}
(Std. Dev.)	*2.93*	*0.87*	*1.48*	*3.35*	*0.73*	*0.50*	*18.70*	*14.63*	*3.58*

[1] attribute that were significantly different than the control treatment ($P<0.05$)
Means with different superscript letters differ ($P<0.05$)
L*- lightness (100 = absolute white to 0 = absolute black), a* - (positive = redness, negative = green intensity), b* - (positive = yellowness, negative = blueness intensity), TP – Total pigment, CP – Cured pigment, PCP – Percent cured pigment

Table 6. Physiochemical Analysis Average aw, TBARS, pH, salt content, and residual nitrite in traditionally-cured (control), natural, and organic bacon.

	Chemical Propterties							
	a_w	TBARS[1]	pH	NaCl[1]	N02[1]	Moisture[1]	Fat[1]	Protein
ID: Code		mg/kg[2]	pH	%	(ppm)	%	%	%
p-value	*0.0896*	*<0.0001*	*0.1449*	*0.0027*	*0.0002*	*0.0024*	*0.0145*	*0.1020*
Control:								
JB	0.94	0.09c	6.04	2.43a	7.06bcd	49.08ab	33.17d	14.34
(Std. Dev.)	0.03	0.02	0.16	0.12	6.20	1.72	2.25	1.19
Natural /	Uncured							
AB	0.92	0.26c	5.90	2.52a	1.24d	50.76a	30.96d	15.20
(Std. Dev.)	*0.03*	*0.03*	*0.13*	*0.14*	*0.76*	*2.76*	*3.40*	*0.91*
CB	0.90	0.14c	6.12	2.10abc	9.27bc	46.11ab	41.03abcd	13.02
(Std. Dev.)	*0.02*	*0.05*	*0.14*	*0.54*	*0.77*	*3.03*	*1.39*	*0.73*
BB	0.85	0.17c	6.00	1.75a	4.07bcd	41.56bcd	42.54abcd	12.07
(Std. Dev.)	*0.01*	*0.01*	*0.12*	*0.24*	*2.00*	*5.74*	*8.64*	*1.37*
DB	0.89	0.15c	6.25	2.32ab	10.69b	45.26ab	37.15cd	13.98
(Std. Dev.)	*0.02*	*0.06*	*0.23*	*0.13*	*7.96*	*2.21*	*2.20*	*1.09*
EB	0.88	0.42bc	6.05	2.26ab	3.18cd	35.62d	47.55abc	11.85
(Std. Dev.)	*0.01*	*0.28*	*0.24*	*0.45*	*2.56*	*5.82*	*8.72*	*1.94*
FB	0.90	0.13c	6.05	2.2ab	4.40bcd	36.13d	49.33ab	11.54
(Std. Dev.)	*0.05*	*0.04*	*0.11*	*0.25*	*0.34*	*3.88*	*5.22*	*1.12*
KB	0.93	0.14c	6.15	2.37a	18.33a	44.44abc	37.83bcd	12.64
(Std. Dev.)	*0.04*	*0.03*	*0.02*	*0.68*	*7.12*	*3.70*	*5.25*	*1.32*
IB	0.94	0.12c	5.96	1.29d	3.29cd	48.29ab	34.96d	13.28
(Std. Dev.)	*0.05*	*0.01*	*0.09*	*0.16*	*2.81*	*6.29*	*10.47*	*3.98*
HB	0.92	1.30b	5.91	2.47a	1.57d	42.77abcd	39.63abcd	13.63
(Std. Dev.)	*0.06*	*1.92*	*0.11*	*0.16*	*0.96*	*11.30*	*15.66*	*3.38*
Organic:								
LB	0.86	3.10a	6.10	2.46a	1.05d	35.16d	51.05a	10.83
(Std. Dev.)	*0.07*	*0.40*	*0.10*	*0.41*	*0.42*	*5.85*	*7.78*	*1.56*
GB	0.90	0.60bc	6.04	1.64cd	2.78cd	36.86cd	48.89ab	10.69
(Std. Dev.)	*0.03*	*0.22*	*0.09*	*0.09*	*1.52*	*1.42*	*1.40*	*0.45*

[1] attribute that were significantly different than the control treatment (P<0.05), [2] mg of malonaldehyde per kg of sample

Means with different superscript letters differ (P<0.05)

a_w – water activity, TBARS – 2-thiobarbituric acid reactive substances, NaCl – salt, N02 – residual nitrite

organic brand (LB) were higher in value and different than the control (JB). Cured pigment concentration and percent cured color were different between brands ($p<0.05$). Cured pigment concentration was found to be different in both organic brands (LB and GB) when compared to the control brand (JB). Evaluation of percent cured color revealed that the means of one natural/uncured brand (AB) and one organic brand (LB) were lower in value and different than the control (JB). The results are in agreement with Sindelar and others (2007a), showing differences for lean objective color, cured pigment, and % converted pigment. However, total pigment was not different as might be expected.

TBARS, Salt Content, Residual Nitrite, Moisture, and Fat

TBARS, salt content, residual nitrite, moisture, and fat were evaluated with pairwise comparison and was found to be different between brand means and control ($p<0.05$) (Table 6). The results suggest that there are differences found in commercial brands. TBARS means for one natural/uncured brand (HB) and one organic brand (LB) were higher and different than the control (JB). Since the values are higher than control, it indicates concern for lipid oxidation and off-flavors. For brand HB, TBARS values indicated that the product had oxidized odor while brand LB values indicated both oxidized odor and flavor. TBARS values reported by Sindelar and others (2007a) also showed differences between commercial uncured, no-nitrate/nitrite added bacon and nitrite-cured bacon. This might be affected by the length of time bacon was shelved in the grocery store. Both of these products were very low in residual nitrite (1.57 ppm and 1.05 ppm), and may have been more susceptible to oxidation as a result. Another explanation of high TBARS could be due to the time and temperature at which the bacon was stored at the market. Three brands of bacon (AB, LB, GB) were stored frozen which can affect TBARS values. One natural brand (IB) and one organic brand (GB) were lower and different than control (JB) for salt content. This indicates some concern for safety with lower salt levels present. One “naturally” cured natural/uncured brand (KB) were higher in value and different than control (JB) for residual nitrite. This could reflect the curing process but could also be the result of the length of time the bacon was shelved in the grocery store. Residual nitrite levels decrease over time. Residual nitrite ranged from 1.05 ppm to 10.69 ppm. This is similar to Sindelar and others (2007a) who reported that residual nitrite ranged from 0.00 to 8.93 ppm in commercial bacon. Two brands of natural/uncured (EB, FB) and both organic brands (LB,GB) were lower in value and different than control (JB) for moisture content. This could have resulted from different raw material composition because pork bellies are recognized as highly variable in composition. Two brands of natural/uncured (EB,FB) and both organic brands (LB,GB) were also higher in value and different than control (JB) for fat content. This correlates to the differences in moisture since these attributes are inversely related.

Correlation of Attributes and Clostridium perfringens

Partial correlation coefficients for the bacon attributes are shown in Table 7. There are positive correlations between the objective color measurements, as might be expected. A positive correlation between total pigment and cured pigment was also observed. With an increase in amount of total pigment available in bacon, more pigment is available to be cured by the addition of nitrite or indirect nitrite. Water activity was positively correlated with moisture and protein, but negatively correlated with fat. An increase in amount of protein creates an increased opportunity for more water to be bound in meat. With more fat, less water can be bound or is less available. These are expected, given the recognized relations between moisture and fat content. TBARS values observed had a positive correlation with

Table 7. Partial correlation coefficients between attributes of bacon

	LL*	La*	Lb*	DL*	Da*	Db*	TP	CP	PCP	a_w
LL*	*1.00*	ns	ns	0.6724	ns	ns	ns	ns	ns	ns
La*	ns	*1.00*	0.5938	ns	0.6123	0.4490	ns	ns	-0.4248	ns
Lb*	ns	0.5938	*1.00*	ns	0.3639*	-0.3275*	0.3677*	ns	-0.4358	ns
DL*	0.6724	ns	ns	*1.00*	-0.3797*	-0.3473*	ns	ns	ns	0.4145
Da*	ns	0.6123	0.3639*	-0.3797*	*1.00*	0.8024	ns	ns	-0.4071	ns
Db*	ns	0.4490	-0.3275*	-0.3473*	0.8024	*1.00*	ns	-0.4302	ns	ns
TP	ns	ns	0.3677*	ns	ns	ns	*1.00*	0.7378	-0.6072	ns
CP	ns	ns	ns	ns	ns	-0.4302	0.7378	*1.00*	ns	ns
PCP	ns	-0.4248	-0.4358	ns	-0.4071	ns	-0.6072	ns	*1.00*	ns
a_w	ns	ns	ns	0.4145	ns	ns	ns	ns	ns	*1.00*
TBARS	ns	ns	ns	ns	ns	ns	0.4755	0.4819	ns	ns
pH	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
NaCl	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
NO2	ns	ns	0.3711*	-0.5153	ns	ns	ns	ns	ns	ns
Moisture	ns	ns	ns	ns	ns	ns	ns	ns	ns	0.5365
Fat	ns	ns	ns	ns	ns	ns	ns	ns	ns	-0.5228
Protein	ns	ns	ns	ns	ns	ns	ns	ns	-0.3610	0.6116

P<0.05, *P<0.10, trend to be significant, ns – not significant, no correlation.
Lighter muscle = LL*- lightness, La* - redness to greenness intensity, Lb* - yellowness to blueness intensity
Darker muscle = DL*- lightness, Da* - redness to greenness intensity, Db* - yellowness to blueness intensity
TP – Total pigment, CP – Cured pigment, PCP – Percent cured pigment
a_w – water activity, TBARS – 2-thiobarbituric acid reactive substances, NaCl – salt, N02 – residual nitrite

Table 7. Partial correlation coefficients between attributes of bacon (continued)

	TBARS	pH	NaCl	NO2	Moisture	Fat	Protein
LL*	ns	ns	ns	ns	ns	ns	ns
La*	ns	ns	ns	ns	ns	ns	ns
Lb*	ns	ns	ns	0.3711*	ns	ns	ns
DL*	ns	ns	ns	-0.5153	ns	ns	ns
Da*	ns	ns	ns	ns	ns	ns	ns
Db*	ns	ns	ns	ns	ns	ns	ns
TP	0.4755	ns	ns	ns	ns	ns	ns
CP	0.4819	ns	ns	ns	ns	ns	ns
PCP	ns	ns	ns	ns	ns	ns	-0.3610*
a_w	ns	ns	ns	ns	0.5365	-0.5228	0.6116
TBARS	*1.00*	ns	ns	ns	-0.5490	0.5416	-0.4539
pH	ns	*1.00*	ns	0.4108	ns	ns	ns
NaCl	ns	ns	*1.00*	ns	ns	ns	ns
NO2	ns	0.4108	ns	*1.00*	ns	ns	ns
Moisture	-0.5490	ns	ns	ns	*1.00*	-0.9675	0.8609
Fat	0.5416	ns	ns	ns	-0.9675	*1.00*	-0.8936
Protein	-0.4539	ns	ns	ns	0.8609	-0.8936	*1.00*

P<0.05, *P<0.10, trend to be significant, ns – not significant, no correlation.
Lighter muscle = LL*- lightness, La* - redness to greenness intensity, Lb* - yellowness to blueness intensity
Darker muscle = DL*- lightness, Da* - redness to greenness intensity, Db* - yellowness to blueness intensity
TP – Total pigment, CP – Cured pigment, PCP – Percent cured pigment
a_w – water activity, TBARS – 2-thiobarbituric acid reactive substances, NaCl – salt, N02 – residual nitrite

Table 8. Correlation coefficients for pathogen growth to physio-chemical traits for bacon of *Clostridium perfringens*. (courtesy of Jackson, 2009)

Attribute	Bacon
a_w	0.347**
pH	0.058
NaCl	- 0.309**
NO2	-0.043
Moisture	-0.05
Fat	0.007
Protein	-0.022

*P<0.05, **P<0.10

a_w – water activity, NaCl – salt, N02 – residual nitrite total pigment, cured pigment, and fat, but were negatively correlated with moisture and protein. Positive correlation between TBARS and color characteristics contradicts what would be expected with increasing rancidity. An increase in fat content increases the risk for lipid oxidation or higher TBARS values to develop. However, higher amount of moisture and protein decreases the amount of fat for lipid oxidation. No correlations for salt content were observed with any other attributes. Residual nitrite had a negative correlation with L value of the obliquus abdominis internus/externus muscle and a positive correlation with pH, but did not show a correlation to other attributes. An increase in amount of residual nitrite should have an effect on color stability. The correlation with pH probably reflects the effect of product pH on residual nitrite. Moisture, fat, and protein were closely correlated with each other, as expected for compositional values that typically total close to 100% of the product composition. The correlations observed help to explain the different physiochemistry relationships.

Partial correlation tables for bacon attributes with growth of inoculated *Clostridium perfringens* (Jackson, 2009) are shown in Table 8. Water activity and salt content showed a trend for significance of growth with 0.347 and -0.209 partial correlation values ($p<0.10$). An increase in water activity would increase concern for bacterial growth due to increased water availability. An increase in salt content suggested a decreased risk for growth as expected. Surprisingly, residual nitrite is not significantly correlated to growth of *C. perfringens*. This contradicts past research but may reflect the low residual nitrite concentrations observed in the bacon samples in this study (Tompkin 2005).

3.5 Conclusions

It is clear that variability exists between brands of commercial natural/uncured and organic bacon. Most of the brands, especially organic brands, appear to be lower in residual nitrite when compared to conventionally cured products, implying that less nitrite was introduced by the natural curing process. On the other hand, one brand (KB) had a higher concentration of residual nitrite when compared to the control. Two brands of bacon (HB, LB) seem to have higher TBARS numbers suggesting lipid oxidation and a faster deterioration of flavor. Because nitrite is necessary for typical cured meat color and flavor, it is not surprising that these quality changes became evident in products with less residual nitrite present. Therefore, microbiological safety may be of concern in these products because residual nitrite is variable between brands as well as some variability in salt concentration. A preliminary inoculation study with commercial bacon that was conducted in parallel with this study indicated that residual nitrite may not be the main indicator for safety in bacon, but suggests that salt and water activity may play key roles in controlling pathogen growth. Other additives may be important to controlling pathogen growth. For emerging commercial brands of bacon, particularly the natural and organic projects, nitrite's action may be reduced by the changes in the process used for these products. Other antimicrobials may need to be considered. Standard guidelines of manufacturing natural/uncured and organic bacon need to be established to address the issue of variability observed in commercial bacon.

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CHAPTER 4. GENERAL CONCLUSIONS

Variability is still being observed in the commercial bacon market. Standard guidelines need to be in place to ensure consistent quality from brand to brand. With processors utilizing new technology and additives a variation of quality and safety issues will arise. Until USDA reports a final ruling on natural/uncured products the issue will still remain. Preliminary inoculation studies also indicate that residual nitrite may not be the main factor for ensuring safety in these new products. More research is needed especially microbial validations of these products.

APPENDIX. RAW DATA: MEANS AND STANDARD DEVIATIONS

Table A1. Averages and standard deviations for traditionally cured, natural, uncured, and organic bacon attributes.

	Obliquus abdominis internus/externus			Cutaneous trunci					
ID	**L***	**a***	**b***	**L***	**a***	**b***	**TP**	**CP**	**PCP**
Control									
JB	40.94	8.85	5.25	52.83	3.87	2.35	63.85	40.07	63.17
(Std. Dev.)	2.86	0.93	0.25	4.70	0.66	0.97	11.86	6.43	5.12
Natural/	**Uncured**								
AB	42.83	8.27	5.84	56.22	2.11	3.24	73.24	31.38	43.24
(Std. Dev.)	*3.03*	*0.61*	*1.22*	*4.09*	*0.45*	*0.72*	*11.22*	*3.53*	*5.55*
CB	42.97	9.40	6.33	52.05	5.13	4.19	68.63	39.58	58.44
(Std. Dev.)	*4.54*	*4.92*	*3.63*	*1.96*	*1.76*	*0.50*	*10.79*	*3.00*	*8.93*
BB	40.99	10.11	6.88	52.78	4.14	2.74	88.21	52.77	62.35
(Std. Dev.)	*3.24*	*0.77*	*0.19*	*6.22*	*0.35*	*0.25*	*24.23*	*1.34*	*13.83*
DB	41.17	8.23	6.56	53.01	3.49	3.70	68.86	44.91	69.98
(Std. Dev.)	*2.36*	*0.78*	*1.39*	*3.60*	*0.88*	*0.44*	*21.67*	*3.49*	*22.97*
EB	41.60	7.90	3.64	53.26	4.80	4.19	80.36	42.74	55.37
(Std. Dev.)	*2.93*	*0.23*	*0.55*	*2.59*	*1.21*	*1.93*	*30.53*	*8.71*	*9.18*
FB	43.96	8.45	7.35	55.47	4.45	5.81	74.69	38.97	54.14
(Std. Dev.)	*1.54*	*1.45*	*0.69*	*1.74*	*1.20*	*1.14*	*28.92*	*11.15*	*8.44*
KB	40.05	8.89	5.82	48.02	3.60	2.44	62.34	40.98	66.24
(Std. Dev.)	*6.51*	*0.78*	*0.73*	*3.84*	*0.70*	*1.15*	*10.26*	*4.85*	*6.57*
IB	45.13	9.69	6.07	58.40	4.28	3.02	64.78	37.90	60.81
(Std. Dev.)	*3.84*	*2.16*	*2.22*	*5.72*	*1.98*	*2.97*	*15.40*	*11.24*	*25.18*
HB	39.93	10.67	6.12	51.02	5.08	4.16	89.71	42.64	48.06
(Std. Dev.)	*5.30*	*2.49*	*2.66*	*2.20*	*1.07*	*1.37*	*33.56*	*13.95*	*3.19*
Organic									
LB	40.39	8.43	7.95	52.56	6.81	7.87	64.40	16.45	25.88
(Std. Dev.)	*1.05*	*0.37*	*0.40*	*2.81*	*1.81*	*0.40*	*15.17*	*2.38*	*2.39*
GB	43.67	10.36	6.94	53.52	4.27	2.79	77.05	55.95	72.50
(Std. Dev.)	*2.93*	*0.87*	*1.48*	*3.35*	*0.73*	*0.50*	*18.70*	*14.63*	*3.58*

L*- lightness (100 = absolute white to 0 = absolute black),
a* - (positive = redness, negative = green intensity),
b* - (positive = yellowness, negative = blueness intensity), TP – Total pigment, CP – Cured pigment,
PCP – Percent cured pigment

Table A1. Averages and standard deviations for traditionally cured, natural, uncured, and organic bacon attributes (continued).

ID	a_w	TBARS	pH	NaCl	NO2	Moisture	Fat	Protein
Control								
JB	0.94	0.09	6.04	2.43	7.06	49.08	33.17	14.34
(Std. Dev.)	0.03	0.02	0.16	0.12	6.20	1.72	2.25	1.19
Natural/	**Uncured**							
AB	0.92	0.26	5.90	2.52	1.24	50.76	30.96	15.20
(Std. Dev.)	*0.03*	*0.03*	*0.13*	*0.14*	*0.76*	*2.76*	*3.40*	*0.91*
CB	0.89	0.14	6.12	2.10	9.27	46.11	41.03	13.02
(Std. Dev.)	*0.02*	*0.05*	*0.14*	*0.54*	*0.77*	*3.03*	*1.39*	*0.73*
BB	0.85	0.17	6.00	1.75	4.07	41.56	42.54	12.07
(Std. Dev.)	*0.01*	*0.01*	*0.12*	*0.24*	*2.00*	*5.74*	*8.64*	*1.37*
DB	0.89	0.15	6.25	2.32	10.69	45.26	37.15	13.98
(Std. Dev.)	*0.02*	*0.06*	*0.23*	*0.13*	*7.96*	*2.21*	*2.20*	*1.09*
EB	0.88	0.42	6.05	2.26	3.18	35.62	47.55	11.85
(Std. Dev.)	*0.01*	*0.28*	*0.24*	*0.45*	*2.56*	*5.82*	*8.72*	*1.94*
FB	0.90	0.13	6.05	2.20	4.40	36.13	49.33	11.54
(Std. Dev.)	*0.05*	*0.04*	*0.11*	*0.25*	*0.34*	*3.88*	*5.22*	*1.12*
KB	0.93	0.14	6.15	2.37	18.33	44.44	37.83	12.64
(Std. Dev.)	*0.04*	*0.03*	*0.02*	*0.68*	*7.12*	*3.70*	*5.25*	*1.32*
IB	0.94	0.12	5.96	1.29	3.29	48.29	34.96	13.28
(Std. Dev.)	*0.05*	*0.01*	*0.09*	*0.16*	*2.81*	*6.29*	*10.47*	*3.98*
HB	0.92	1.30	5.91	2.47	1.57	42.77	39.63	13.63
(Std. Dev.)	*0.06*	*1.92*	*0.11*	*0.16*	*0.96*	*11.30*	*15.66*	*3.38*
Organic								
LB	0.86	3.10	6.10	2.46	1.05	35.16	51.05	10.83
(Std. Dev.)	*0.07*	*0.40*	*0.10*	*0.41*	*0.42*	*5.85*	*7.78*	*1.56*
GB	0.90	0.60	6.04	1.64	2.78	36.86	48.89	10.69
(Std. Dev.)	*0.03*	*0.22*	*0.09*	*0.09*	*1.52*	*1.42*	*1.40*	*0.45*

a_w – water activity, TBARS – 2-thiobarbituric acid reactive substances, NaCl – salt, N02 – residual nitrite pigment

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